STRUCTURE AND INFRASTRUCTURE ENGINEERING
https://doi.org/10.1080/15732479.2020.1768272

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Model reduction for structural health monitoring accounting for soil-structure-interaction

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ABSTRACT

This work addresses structural model reduction, a process necessary in structural health monitoring, where large quantities of data are recorded and must be evaluated. Therefore, numerical modelling of a structure is necessary for processing the recorded data and for estimating structural degradation over time. In order to avoid complex structural models and to economize computational resources, reduced order models have to be introduced. The goal is to develop a replacement single-degree-of-freedom oscillator that takes into account soil-structure-interaction effects. The dynamic characteristics of this oscillator are estimated by using the total displacement equality criterion. More specifically, the replacement process exhibits the following characteristics: (i) The complete time history of the "equality parameter" is considered and not just the resonance amplitudes; (ii) the problem is solved in the frequency domain using the complete set of the equations of motion; (iii) the outcome is independent of the excitation motion; (iv) the method can be applied for any mechanical parameter desired; and (v) the foundation impedance matrix is included. Following this development, parametric studies are conducted for assessing the dependency of the dynamic properties of the equivalent oscillator on the soil profile, the inertial characteristics of the foundation and its embedment depth.

ARTICLE HISTORY
Received 20 December 2019
Revised 26 February 2020
Accepted 30 March 2020

KEYWORDS
Effective properties; embedded foundations; replacement oscillator; soil-structure-interaction; structural health monitoring

1. Introduction

Civil engineering infrastructure throughout its useful lifetime is exposed to various environmentally-induced external loads, such as wind pressures, temperature variations, earthquake motions, ground settlements, etc. The structure's bearing capacity and the intensity of the external loads are two interrelated parameters that pay a pivotal role in determining whether or not the structure in question remains functional. In this respect, Structural Health Monitoring (SHM) is a powerful diagnostic tool for damage detection and its operational protocol can be divided into four key steps: (i) Data acquisition; (ii) system identification; (iii) condition assessment; and (iv) decision making (Farrar & Worden, 2012; Sony, Laventure, & Sadhu, 2019). During any of the aforementioned steps, the parallel use of a structural model may be either an auxiliary tool or even an essential one (Ghahari, Abazarsa, Avci, Celebi, & Taciroglou, 2016; Taciroglu, Celebi, Ghahari, & Abazarsa, 2016).

New developments in the field of SHM (Lynch & Loh, 2006; Smarsly & Law, 2013) focus on: (i) wireless sensors that transmit recorded data to a central unit after initial processing and on (ii) artificial intelligence (AI), where the data stream coming from the sensors is evaluated and used in decision making. Although structural modelling is not a prerequisite for AI procedures that basically do data stream optimization so as to spot trends in the underlying structural response, the former may be useful for preliminary data evaluation. Thus, the criteria for choosing a structural model for SHM purposes can be summarized as follows: (i) the model must simplify the inherent complexity in the original structural systems; (ii) it must reduce large scale computations and minimize computational time requirements; (iii) it must finally minimize power demands posed on the continuous transmission operation by the sensors, which at the same time have to perform some rudimentary calculations. The structural models used for this purpose may be analytical, numerical or possibly a combination of both types.

In many cases, the structural system under scrutiny is founded on weak soil formations necessitating the consideration of soil-structure-interaction (SSI) effects. For the numerical analysis of the combined structure-foundation-soil system, two categories of models are available (Johnson, 1981): (i) The direct approach, where the combined system is discretized using the finite element method (FEM); (ii) the sub-structuring approach, where each component is separately modelled by semi-analytical or discrete models and subsequently combined using compatibility and equilibrium conditions at the common interfaces. The sub-structuring approach is more versatile and can be used with various simplifications in the preliminary design stage, where the engineer wishes to have an estimate of the expected

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/15732479.2020.1768272.